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(54) METHODS, APPARATUS AND SYSTEMS FOR ENHANCED SYNTHETIC VISION AND MULTI-SENSOR DATA FUSION TO IMPROVE OPERATIONAL CAPABILITIES OF UNMANNED AERIAL VEHICLES

VERFAHREN, VORRICHTUNGEN UND SYSTEME FÜR VERBESSERTE SYNTHETISCHE VISIONEN UND MULTISENSOR-DATENFUSIONEN ZUR VERBESSERUNG DER BETRIEBLICHEN FUNKTIONEN UNBEMANNTER FLUGKÖRPER

PROCÉDÉS, APPAREILS ET SYSTÈMES DE VISION SYNTHÉTIQUE RENFORCÉE ET FUSION DE DONNÉES DE MULTIPLES CAPTEURS POUR AMÉLIORER LES CAPACITÉS OPÉRATIONNELLES DE VÉHICULES AÉRIENS SANS PILOTE

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(56) References cited:
WO-A2-01/58758 **US-A- 5 933 120**
US-A- 6 064 428 **US-A1- 2005 113 987**
US-B2- 7 131 136

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Description

Background of the Invention

[0001] Unmanned aerial vehicles (UAVs) have demonstrated great potential for various surveillance and reconnaissance military applications due to their growing capabilities and lower cost of operation. However, there are a number of technical constraints hindering their widespread acceptance. These include issues associated with operational effectiveness, use of data, and National Airspace access, to name a few.

[0002] Thus, for example, small UAVs have substantially reduced the cost of Line Of Sight (LOS) surveillance and reconnaissance missions, but still have difficulties integrating data-link bandwidth limitations, Beyond Line Of Sight (BLOS), traffic detection and avoidance, as well as more airborne intelligence with navigation capabilities. Most or all of these issues have not really been resolved with either reliable and/or affordable technology.

[0003] An object of the invention is to provide improved methods, apparatus and systems for unmanned aerial vehicle operation. A related object is to provide such improved methods, apparatus and systems as can be used with small UAVs.

[0004] Still further objects of the invention provide such improved methods, apparatus and systems as improve small UAVs' mission capabilities, as well as their provision of actionable intelligence.

[0005] US2005/113987A1 discloses a multi-agent autonomous system for exploration of hazardous or inaccessible locations, including simple surface-based agents or craft controlled by an airborne tracking and command system. The latter includes an instrument suite used to image an operational area and any craft deployed within the operational area. The image data is used to identify the craft, targets for exploration, and obstacles in the operational area. The tracking and command system determines paths for the surface-based craft using the identified targets and obstacles and commands the craft using simple movement commands to move through the operational area to the targets while avoiding the obstacles. Each craft includes its own instrument suite to collect information about the operational area that is transmitted back to the tracking and command system.

[0006] WO0158758A2 discloses a solar rechargeable aircraft that can remain airborne almost indefinitely. The aircraft can serve as a long term high altitude platform that serves to link a ground station using radio wave signals and a satellite using optical signals. The aircraft can be remotely piloted through multiple, redundant communication subsystems. The availability and reliability of each separate communication subsystem is continuously monitored.

[0007] US6064428A discloses an automated track inspection vehicle for inspecting track for anomalies which includes a self-propelled car equipped with cameras for creating images of the track. Images from the cameras are viewed by an inspector on a video terminal to detect anomalies. When anomalies are detected by the driver, inspector, or various redundant detection systems, a signal is provided to store the video data for later review by an analyst. The analyst will review the stored video data to confirm the presence of an anomaly and generate a track inspection report identifying at least the type and location of anomaly and the required remedial action.

Summary of the Invention

[0008] The foregoing are among the objects attained by the invention which provides, in some aspects, improved methods, apparatus and systems for unmanned aerial vehicle (UAV) operation that utilize multiple data links between a UAV and a control station in order to transmit control and actionable intelligence data. Such methods, apparatus and systems can be used, for example, to monitor a selected environment (e.g., an oil field or other terrain/environment of interest). In a related aspect, such data links comprise satellite communication channels.

[0009] Related aspects of the invention provide such methods, apparatus and systems that use a first of the data links (e.g., satellite communication channel) for transmission of command, control and/or system monitoring data. A second one of those data links can be used for transmission of actionable intelligence data.

[0010] Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the UAV includes an onboard transceiver (e.g., low-orbit satellite modem) that transmits to the control station the aforementioned command, control, system monitoring, and/or actionable intelligence data.

[0011] Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the UAV includes an airborne imaging computer that acquires and/or analyzes images from onboard cameras (and other sensors). In a related aspect, the airborne imaging computer identifies actionable intelligence data, e.g., via anomaly detection.

[0012] Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the imaging computer discerns coordinates of the detected anomalies and/or other actionable intelligence.

[0013] Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the imaging computer effects transmission of actionable intelligence data and the coordinates to the control station. In a related aspect of the invention, such actionable intelligence data can include images, e.g., video and/or stills, acquired by the UAV's onboard sensors. In a further related aspect of the invention, such actionable intelligence data can include portions of video and/or still images representing anomalies in a terrain/environment in a vicinity of the UAV.

[0014] Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, wherein the imaging computer (or other component of the UAV) transmits coordinate data to the control station over the aforementioned first data link, and images comprising the actionable intelligence data over the aforementioned second data link.

[0015] Further aspects of the invention provide improved methods, apparatus and systems for UAV operation, e.g., as described above, that includes functionality for detecting anomalies in the images and/or other sensor data.

[0016] Further aspects of the invention provide improved methods, apparatus and system for UAV operation, e.g., as described above, wherein the control station includes a synthetic vision display system that enhances a synthetic display of terrain over which the UAV is flying and/or in which an anomaly is detected with image and/or coordinate data received from the UAV. This can be used, for example, to (i) eliminate the necessity of transmitting to the control station a high-bandwidth and/or real-time stream of images representing, e.g., the terrain/environment in a vicinity of the UAV, in favor of only selected events detected in that vicinity, and (ii) focus a control station operator's attention when an actionable intelligence event occurs.

[0017] Further aspects of the invention provide improved methods, apparatus and system for UAV operation, e.g., as described above, wherein the synthetic vision display system includes a terrain database for rendering a synthetic image based on a location of the UAV (e.g., as indicated via GPS coordinates transmitted over one or more of the data links).

[0018] Further aspects of the invention are evident in the drawings and the description that follows.

Brief Description of the Drawings

[0019] A more complete understanding of the invention may be attained by reference to the drawings, in which:

Figure 1 depicts an autonomous small unmanned vehicle system (SUAS) according to one practice of the invention;

Figure 2 depicts further details of an exemplary aircraft of the type used in one practice of the invention;

Figure 3 depicts in further detail the interrelationships among selected ones of the aircraft-based elements shown in Figure 1;

Figure 4 depicts the SUAS system of Figure 1 from the perspective of the ground control station;

Figure 5 depicts a flow diagram of a synthetic vision system according to the invention;

Figure 6a depicts a FLIR-based Enhanced Synthetic image of the type generated by a system according to the invention;

Figure 6b depicts a terrain morphing image of the type generated by a system according to the invention;

Figure 7 depicts dynamic terrain awareness image of the type generated by a system according to the invention;

Figure 8 depicts a traffic display overlay image of the type generated by a system according to the invention;

Figure 9 depicts an integrated synthetic image of the type generated by a system according to the invention;

Figure 10 depicts an image generated in connection with an anomaly-based alarm by a system according to the invention; and

Figures 11 - 13 depict aspects of an airborne processor that can be used with practice of the invention.

Detailed Description of the Illustrated Embodiment

[0020] Figure 1 depicts an autonomous small unmanned vehicle system (SUAS) according to one practice of the invention suitable for remote inspection, surveillance, reconnaissance and other applications (collectively, "surveillance"). The illustrated system 10 comprises the following integrated elements, though, it will be appreciated that other embodiments may include other elements, instead or in addition, and/or may include subsets of those shown below:

1. A small unmanned aircraft 12 capable of autonomous flight and equipped with an airborne video camera.

2. An airborne computer 14 that is capable of acquiring, compressing, storing and processing analog and digital video.

3. Anomaly detection software executing on computer 14.

4. Airborne low-orbit satellite modem(s) 16.

5. A ground control station 18 connected via satellite with software capable of visualizing navigation and payload data as an overlay to three dimensional ter-

rain display 20.

The Unmanned Aircraft

[0021] Unmanned aircraft 12 (alternatively, referred to as the "UAV") may be of the type commonly known for use in SUAS systems (e.g., by way of non-limiting example, the Vector P UAV available from Intellitech Microsystems). Though craft 12 utilized in the illustrated embodiment is small of size (relative to manned aircraft), other embodiments may utilize larger craft, while other embodiments may utilize craft even smaller than that depicted in the drawings. Moreover, although illustrated craft 12 is unmanned (i.e., does not have an onboard human pilot), in other embodiments such a pilot and/or personnel other may be onboard. Still further, although illustrated craft 12 is an aircraft, it will be appreciated that in other embodiments, craft 12 may operate in other environments, e.g., water, land, and so forth. Yet still further, while illustrated craft 12 is intended for operation remote from the ground control station, in other embodiments the craft 12 may be used for nearby operations - albeit, for example, operations in which it is less preferable to expose ground control station operators and/or their equipment). For sake of simplicity, both remote and nearby operations are referred to herein as "remote."

[0022] Figure 2 depicts further details of an exemplary aircraft 12 of the type used in one practice of the invention. As shown in the drawing, illustrated craft 12 includes avionics section 22, fuel tank 24, satellite communications subsystem 26, stabilized gimbal assembly 28, satellite antenna structure 30, collision avoidance sensors 32 and mode C transponder 34, all of the type known in the art as adapted in accord with the teachings hereof. Thus, for example, antenna structure 30 of the illustrated embodiment comprises dual antennae, capable of supporting dual low-orbit (or other) satellite communications (e.g., with one antenna supporting the communication of command & control information, and the other antenna supporting communication of alarms and related data). In order to conserve space and power, the individual antenna used in the illustrated embodiment are "small" disk-shaped antenna having diameters of approximately 3" or less. Other embodiments may vary in this regard, e.g., utilizing antenna of diameters of 4" or less, 5" or less, 10" or less, and so forth. As noted above, other embodiments of the invention may include elements other than those shown in Figure 2, instead or in addition, and/or may include subsets of those shown in the drawing.

[0023] Aircraft 12 additionally includes mission computer 14, as shown, which can comprises a portable computer or other digital data processor of the type commercially available in the marketplace as programmed and otherwise adapted in accord with the teachings hereof. Preferred such computers are ruggedized for tolerance of inflight conditions and include graphics cards to facilitate anomaly detection and other processing functions described herein.

[0024] Figure 3 depicts in further detail the interrelationships among selected ones of the aircraft-based elements shown in Figure 1. Particularly, as shown in Figure 3, mission computer 14 is coupled by way of a bus 27 to video processor 28, storage unit 30, inertial navigation system (INS) - global positioning system (GPS) system 32, and dual satellite communications modems 34, 36. Elements 28 - 36 are of the respective types known in the art, as adapted in accord with the teachings hereof. Thus, again, for example, although the prior art typically provides a single SATCOM modem, the illustrated embodiment utilizes two such modems 34, 36 (each supporting low-speed communications, e.g., at a rate of approximately 9600 bps - as discussed elsewhere herein), e.g., one supporting the transfer of command & control information with the GCS and the other supporting the transfer of alarms, alarm images and related data with the GCS. By way of further example, storage unit 30 may comprise an on-board disk drive that stores a video stream of the entire flight which can then be post-processed using change-detection to identify possible threats that were too subtle to detect in real time.

[0025] Bus 27 of the illustrated embodiment is a PCI/PCI-Express bus, though, in other embodiments, other bus types or communication media may be used, instead or in addition.

[0026] With further reference to the drawing, INS-GPS unit 32 is coupled to a GPS antenna, as shown. In addition, mission computer 14 is coupled to airborne video camera 38 (or other image acquisition device) by way of video processor 28. The video camera 38, which is disposed on or otherwise coupled to craft 12, acquires images of terrain, airspace, or other scenes in a vicinity of the craft 12 (and, more particularly, in a field of view of the camera 38) suitable processing by the mission computer 14 and/or transmission to the GCS 18). Video camera 38 may be of the type commonly used in airborne or other remote image acquisition (and, preferably, video image acquisition) applications and, particularly, of the type that generates a "true color" three-band (RGB) image. Video processor 28 may be of the type commonly used for interfacing a video (or other) image acquisition device with a computer for purposes of control and data transfer. Coupling between the video processor 28 and the video camera 38 may be via FireWire or other interface (wired, wireless or otherwise) known in the art.

[0027] Mission computer 14 is also coupled with autopilot systems 40, 42 (each of the type known in the art) which, themselves, are coupled to airborne heading-attitude reference systems (AHARS) 44, 46 and GPS antenna, as shown. In the illustrated embodiment, communications between the mission computer 14 and the autopilot systems 40, 42 is supported by dual ethernet channels 48, 50, though, in other embodiments, other media may provide such support.

[0028] Although in the illustrated embodiment, mission computer 14, video processor 28 and video camera 38 are disposed on craft 12 and in wired communications with one another, in other embodiments one or more of those elements be disposed elsewhere. Thus, for example, camera 38 may be disposed on craft 12, while mission computer 14 and video processor 28 are disposed on another craft (not shown) or intermediate station (not shown) in sufficient proximity to permit transmission of high resolution images from camera 38 to the mission computer 14 for processing and anomaly detection thereby.

[0029] In the illustrated embodiment, camera 38 is housed in the gimbaled assembly 28, which is attached to the underside of the craft's fuselage. The gimbal 28 preferably includes an integrated Global Positioning System/Inertial Measurement Unit system (GPS/IMU) and is stabilized using feedback logic that links the gimbal's servo-motors and the IMU under software control. Furthermore, the gimbal's integrated GPS can be used to determine the geographical location of the center of the video image.

[0030] Anomaly detection software executing on mission computer 14 of the illustrated embodiment utilizes both spectral and spatial methods, as well as supervised and unsupervised classification techniques. It is based on the SSRX (subspace RX) algorithm (or methodology) known in the art (e.g., as disclosed in Winter et al, "Hyperspectral image sharpening using multispectral data," Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XI, Proceedings of the SPIE, Volume 5806, pp. 794-803 (2005)) and on the open source RXD algorithm (or methodology), e.g., as disclosed in I. S. Reed and X. Yu, "Adaptive multiple-band CFAR detection of an optical pattern with unknown spectral distribution," IEEE Trans. Acoust.,Speech, Signal Processing, vol. 38, pp. 1760-1770, Oct. 1990, that was originally developed to detect anomalies in images generated by hyper-spectral cameras.

[0031] In the illustrated embodiment, SSRX is novelly applied to the RGB color video from camera 38 (and video processor 28), and it is adapted to identify anomalies whose Mahalanobis distances correlate with actual or suspected alarm instances (e.g., intrusions or other suspect patterns in video images by the camera 38), e.g., as determined empirically or otherwise based on the expected content of video images in which anomalies are being detected.

[0032] In the illustrated embodiment, the occurrence of false alarms (i.e., signaling of false anomalies) otherwise evidenced in the SSRX image (i.e., the image resulting from SSRX processing) is further eliminated through spatial filtering. This is done using image pyramids of the type known in the art. More particularly, it is done by cycling through image pyramids in the SSRX image. This eliminates artifacts and objects of small width in the filtered image that results from the SSRX processing - and, conversely, emphasize objects in that filtered image that have a blob-like geometry. Pixels within regions of the image that remain after such spatial filtering are, then, highlighted in the original video image of the scene so as to call them out as alarms.

<u>The Ground Control Station</u>

[0033] Figure 4 depicts the SUAS system 10 of Figure 1 from the perspective of the ground control station. Although in the illustrated embodiment, this is contemplated to be a station disposed at a ground-based site, in other embodiments it may be disposed in the air or elsewhere. Regardless, for sake of simplicity, it shall be referred to herein as a "ground control station" or "control station."

[0034] As noted previously, the system 10 includes a unmanned craft 12 that is coupled for communications with a ground control station 18 via radio frequency (RF) and satellite (SATCOM) links. In the drawing, the former is graphically depicted by a dish antenna 60 coupled with computer 17 at the GCS, though, those skilled in the art will appreciate that such an RF (of alternate) link may be supported in other ways. Likewise, the latter is graphically depicted by a satellite 62 (e.g, supporting both the transfer of command & control information, as well as alarms, alarm images and related data), though, such an alternate link may be provided instead or in addition. Indeed, as noted above, in the embodiments of Figures 1 - 3, dual satellite links are provided between the craft 12 and the GCS 18.

[0035] Computer 17 comprises a portable computer (e.g., of the laptop, ruggedized backpack portable computer, or other variety) of the type commercially available in the marketplace as programmed and otherwise adapted in accord with the teachings hereof. To that end, illustrated computer 17 includes command and control subsystem 62, image processing subsystem 64 and image storage subsystem 66. Each of these subsystems may execute in software, firmware or otherwise on separate processor boards (e.g., co-processing cards) resident in the computer 17, as suggested in the drawing, or, alternatively, two or more of them may execute on a common board (e.g., a motherboard).

[0036] Illustrated command and control subsystem 62 comprises logic for interfacing with the flight and other operational functions of craft 17, e.g., over a first of the SATCOM links, to facilitate the transfer of command & control information therewith. It can be constructed and operated in the conventional manner known in the art, as adapted in accord with the teachings hereof.

[0037] Image processing subsystem 64 comprises logic for processing images relayed from the craft 12 to the GCS, e.g., over a second of the SATCOM links, as well as for generating images based on alarm data and/or images supplied by the craft 12 and/or the image storage subsystem 66.

[0038] Illustrated image storage subsystem 66 stores images relayed from the craft 12, as well as those generated by the image processing subsystem 64. In addition, disk drives and other media in the image storage subsystem can retain terrain, obstacle and other databases utilized in operation of the system.

[0039] The computer 17 is coupled to one or more displays, which may be integral to the computer (as in the case of a laptop computer) or separate. Two exemplary images generated by the computer 17 on such displays are shown in the drawing: a video display image 68 depicting a scene in the vicinity of craft 12 (e.g., highlighting an alarm or other event of interest) and a command & control image 70 for situational awareness. Of course, it will be appreciate that these images are merely shown by way of non-limiting example of the types of images generated by computer 17 for use by GCS personnel.

[0040] As further shown in the drawing, computer 17 may be coupled to remote SATCOM server 72 by way of network 74 or otherwise.

[0041] Figure 5 is a flow diagram of a three-dimensional (3D) synthetic vision system 80 executing within image processing subsystem 64 on the computer 17 at the ground control station to permit an operator to visualize events happening in and around the operating aircraft 12 or regions in which it detects alarms. Examples of the images generated by system 80 are provided in Figures 6a, 6b, 7, 8, 9 and 10, discussed elsewhere herein.

[0042] The system 80 includes a 3D image reconstruction engine 82 that takes input from terrain database and obstacle databases 84, 86, respectively, as well as from navigation database 88, as shown. The engine 82 also takes input from data sources 90 that include, in the illustrated embodiment, aircraft navigation data 92, payload sensor data 94 and net-centric data 96, again, as shown. In the illustrated embodiment, the aircraft navigation data 92 and payload sensor data 94 are supplied from the craft 17, e.g., via the SATCOM link. The engine 82 generates a 3D scene graph 98, e.g., for use in generating displays, e.g., on a console coupled to GCS computer 17.

[0043] Terrain database 84 and obstacle database 86 of the illustrated embodiment comprises digital elevation model terrain and obstacle data, respectively, which may be compliant, for example, with DO 200A standards, as illustrated, or otherwise. The terrain database 84 is subject to two constraints: resolution and integrity. The Digital Elevation Model (DEM) and the Digital Terrain Elevation Data (DTED) Level drive the resolution. DTED Level [1, 2 up to 5] determines the resolution of the grid of points. For instance, DTED Level 1 is the basic resolution for elevation and/or terrain roughness in a digital format. DTED1 is a uniform matrix of terrain elevation values with post spacing every 3 arc seconds (approximately 90 meters). This level is most adequate when flying at several thousand feet and looking at mountains, but would not be suitable to land an aircraft in a non-airport environment.

[0044] Obstacle database 86 represents all forms of terrain and other items that can be a potential hazard to aircraft landing at a particular airport or otherwise traveling through airspace in which the craft is expected to fly. Television and radio antennas, tall buildings and plants, for example, are preferably precisely located and represented in the database 86 so that they can be displayed in order to be avoided.

[0045] In case of military applications, net-centric data of interest can be incorporated into the scene graphs 98 for display in scenery.

[0046] Navigation database 88 may comprise Digital Aeronautical Flight Information File (DAFIF) data on airports, navaids, waypoints, special-use airspace, and so forth, and other navigational data from National Geodetic Survey (NGS) and Jeppesen, and so forth. Navigation databases 18 may not be very important when flying a UAV in certain military situations, but are more relevant when a small UAV is flying inside National Airspace. For instance, a small UAV flying under a FAA Certificate Of Authorization (COA) must be aware of the surrounding airspace (i.e. airport class, communication requirements, approaches, way-points, procedures, radio frequencies etc.)

Operation

[0047] Most prior art UAVs send video in real time to their associated GCS using a line-of-sight (LOS) data link. The bandwidth limitations of small UAVs make beyond-line-of-sight (BLOS) operations nearly impossible using commercial, low-orbit satellite communications (SATCOM), which are typically limited to 9600 bps (bytes per second) throughput and, hence, are considered to be "low speed" links (e.g., relative to modern network and data link communications speeds) .

[0048] The illustrated embodiment overcomes these limitations utilizing the architecture shown in Figures 1 and 4. The mission computer 14 uses anomaly detection software to identify high-risk targets in the video image acquired by camera 38 (and video processor 28) and to send alarms (or "actionable intelligence" data) to the GCS using the SATCOM link. That link, in the illustrated embodiment, is low-speed, i.e., it has a throughput of 9600 bps, though, other embodiments may vary from this. These alarms can identify the actual or suspected nature of the anomaly, as well as the location where it was detected. In addition, the alarm can be supplemented by a highly compressed color image that is transmitted to the GCS via the SATCOM link and that shows both an entire video frame including the anomaly. Alternatively, or in addition, if the craft 12 is within line-of-sight of the GCS 18, the alarm can be supplanted via an image or video stream transmitted from the craft to the GCS via the RF data link. The alarm and, if available, the corresponding image are displayed by computer 17 at the GCS, along with locational information derived from the on-board integrated GPS/IMU system - or, in preferred embodiments, along with a three-dimensional synthetic image constructed by system 80 utilizing the terrain, obstacle and/or navigation databases of a scene of the terrain (or other region) in which the alarm occurred.

[0049] Alternatively, or in addition, the system 80 can utilize inflight navigational data supplied by the craft 12, in conjunction with data from the terrain, obstacle and/or navigational databases, to generate three-dimensional synthetic images of the airspace and/or terrain in a vicinity of the craft 12. Those images can be enhanced to facilitate operational awareness as discussed below.

[0050] In operation, the craft 12 is launched and recovered using radio control (RC) in the conventional manner known in the art. Once stable flight has been established, control is transferred to one of the on-board autopilot systems 40, with the other autopilot system 42 serving as a backup. The autopilots 40, 42 of the illustrated embodiment are preprogrammed with way points that trace the location of a corridor or other region over which flight is to occur. Such a corridor may be, for example, a right-of-way for electricity, crude oil, petroleum, natural gas, and so forth, requiring inspection. The location of one or more emergency recovery areas may also pre-programmed into the autopilots in case emergency situations occur.

[0051] The way points as well as other autopilot functions can be altered in flight from the ground control station (GCS) via the satellite communications (SATCOM) link, shown here supported by onboard modems 34, 36 and antenna 30, as well as by the "SATCOM Data-Link" depicted in GCS 18. This capability can be used when the on-board real-time processor 14 detects an alarm in the corridor or other region being surveyed and the GCS operator decides another look is required. The GCS-based operator can then instruct the craft (via the SATCOM link) to fly a circular pattern centered on the alarm's location and keeping the gimbaled camera aimed at that location.

[0052] As noted above, the mission computer 14 uses the anomaly detection software to identify high-risk targets in the video image acquired by camera 38 (and video processor 28) and to then raise an alarm to the operator at the GCS 18 via transmission over the SATCOM link identify the actual or suspected nature of the anomaly, as well as the location where it was detected.

[0053] This alarm can be supplemented by sending a highly compressed color image (referred to as an "alarm image"), again, over the SATCOM link, with a video frame showing the suspected anomaly. An example of such an image is shown in Figure 10. This alarm image shows two cars 52, 54 that have been parked in the right-of-way 56 (demarked by dashed line). The anomaly detection software has detected the cars 53, 54, marked them with black highlights (not shown) and notified the GCS computer 17 of the detection. Alternatively, or in addition, if the craft 12 is within line-of-sight of the GCS 18, the alarm can be supplanted via an image or video stream transmitted from the craft to the GCS via the RF data link.

[0054] The alarm and, if available, the alarm image, is displayed at the GCS, along with locational information derived from the on-board integrated GPS/IMU system - or, in preferred embodiments, along with a three-dimensional synthetic image constructed by system 80 utilizing the terrain, obstacle and/or navigation databases of a scene of the terrain (or other region) where the alarm occurred. Such an image is depicted in Figure 9, showing not only a synthetic image display of the region in vicinity of the craft 12 and an alarm, but also the location of the alarm 122 and an alarm image 124 pertaining thereto.

[0055] The GCS operator can act immediately on the alarm and/or superimpose such an image onto images captured on previous flights and then determine if the alarm poses an imminent danger. If necessary, the GCS operator can instruct the craft 12 to return to the target and capture additional imagery.

[0056] A typical mission by craft 12 can take approximately four hours to fly. After the craft 12 has landed, the disk drive 30 is removed and the digital AVI files are transferred to a computer 17 at the GCS, which can use a hardware accelerator board (not shown) to perform real-time video enhancement, fusion, stabilization and mosaicking, and to place the processed video into a geospatial context so it can be directly compared with video taken during previous flights. Classical change detection algorithms of the type known in the art is then used to identify video segments that a video analysts would then manually review.

Data Fusion and Enhanced Vision

[0057] UAV 12, in many applications, needs to land in non-controlled environments such as an unimproved landing strip. It is necessary that the system "knows" its landing environment with enough details (i.e. enough resolution) to land safely. To this end, three-dimensional (3D) synthetic vision system 80 can generate an image depicting the airspace and/or terrain in and around craft 12 that fuses synthetic vision frames with Forward Looking Infra Red (FLIR) images. Such an image is depicted in Figure 6a. It includes an outer frame 100 comprising a FLIR image sent from the UAV 12 to the CGS computer 17, on which is superimposed an inner frame 102 comprising a three-dimensional synthetic image generated by system 80 for the corresponding vantage point from which the FLIR image was captured.

[0058] A system 10 having this capability is referred to as an Enhanced and Synthetic Vision System (ESVS) and provides the ability to display transient elements in a real-time scene and highlight potential landing hazards. In addition to improving safety, the imagery can be analyzed in real time by an operator or logic executing on computer 17 to detect anomalous components in a particular scene.

[0059] The use of a real-time terrain-morphing engine that combines sensors such as scanning radar or LIDAR data with synthetic vision frames is also of interest in mountainous areas where terrain altitude may vary rapidly or where rough surfaces exists with rocks and or debris. This can be used, for example, to aid landing for helicopters operating in brownouts or whiteout conditions by bringing the terrain resolution at 30 cm and therefore substantially improve the "terrain knowledge" where an aircraft plans to land.

[0060] To this end, three-dimensional (3D) synthetic vision system 80 can generate an image that superimposes a three-dimensional image generated from scanning radar or LIDAR data with a three-dimensional synthetic image generated from the terrain, obstacle and/or navigational databases 84, 86, for the corresponding locale in the vicinity of craft 12. Such an image is shown in Figure 6b, including detailed regions 104 generated from scanning radar or LIDAR data and less detailed regions 106 generated from the databases 84, 86, 88. Use of such images substantially increase operational capabilities and safety in landing in unprepared/unimproved landing sites.

Terrain and Traffic Avoidance

[0061] A Terrain Awareness Warning System (TAWS) helps avoid Controlled Flight Into Terrain (CFIT). The illustrated embodiment includes a TAWS option to enable to operator to configure the dynamic coloration of the terrain based on the relative altitude of the aircraft Above Ground Level (AGL) as shown in Figure 7. Referring to that drawing, terrain 110 below a first specified height is tinted in a first color (e.g., green) in synthetic images of terrain in vicinity of the craft 12; terrain 112 above the first specified height, but below a second specified height is tinted in a second color (e.g., yellow); terrain 114 above the second specified height is depicted in a third color, e.g., red.

[0062] The three-dimensional (3D) synthetic vision system 80 of the illustrated embodiment can generate images, such as those shown in Figure 7, that provide for such dynamic visual terrain awareness. This can be augmented (e.g., by logic and sound cards executing and computer 17) with audio advisory when the system detects a path potentially leading to Controlled Flight Into Terrain (CFIT). The use of a high integrity airborne terrain database 84 correlated with inertial and GPS data provided by craft 12 provides a high level of autonomous terrain awareness in addition to the mission controller display.

[0063] The FAA requires that unmanned aerial vehicles provide an Equivalent Level Of Safety as a manned aircraft regarding the See and Avoid regulations. In a manned aircraft, the "see-and-avoid" function is provided by the Pilot In Command (PIC) and is his direct responsibility. The illustrated SUAS system 10 replicates the see and avoid function inside the UAV 12 with one or multiple sensors (such as an active collision avoidance system for non-collaborative targets, as well as an ADS-B transceiver or a Mode C transponder) to detect other traffic and perform appropriate avoidance maneuvers.

[0064] To this end, the three-dimensional (3D) synthetic vision system 80 of the illustrated embodiment can generate images, such as those shown in Figure 8, that provide for such display including real-time detected traffic 116, the relative positions of of that traffic and craft 12. In embodiments, where a ground radar provides coverage for a flight zone, traffic detected by that radar is also integrated into images of the type generated by system 80 and shown in Figure 8. Logic executing on computer 17 can additionally determine if there are any conflict between data sources.

Highway In The Sky & Guided Approaches

[0065] One of the operational issues associated with small UAVs is the relatively high responsibility placed on individuals for various operational phases such as preflight, take off and landing. In today's environment, a typical system would include at least a pilot, perhaps a preflight technician, a mission controller, and a radar specialist for airspace de-confliction. In order to reduce the manual operations associated with a particular mission, more automation is needed at several levels.

[0066] Referring to Figure 9, the three-dimensional (3D) synthetic vision system 80 can generate images depicting airspace and/or terrain in and around the operating aircraft 12 that include a "Highway-In-The-Sky" (HITS) visualization scheme to identify safe flight pathways and landing approaches. Where used with approaches, these are specifically designed to land the UAV 12 safely, taking in account surrounding terrain, obstacles and any other areas of concern.

Integrating Navigation and Actionable Intelligence

[0067] The primary purpose of the UAV 12 is to gather data, and the system 10 must translate this gathered data into actionable intelligence. Operators at the GCS 18, however, must maintain control on both navigation and mission. The three-dimensional (3D) synthetic vision system 80 generates images of the type shown in in Figure 9 to integrate this information into a montage that permits the operators to conduct the mission while maintaining a high level of situational awareness. By way of example, Figure 9 is a three-dimensional synthetic image showing the airspace and terrain in vicinity of craft 12, along with a HITS display to landing (as discussed above), a projected landing zone 118, a demarcation of a projected flight plan 120, the location of an alarm 122 and an enhanced image of the corresponding anomaly 124, and a video feed 126 from a region within the flight plan.

[0068] Such an image may be generated on displays coupled to GCS computer 17, as well as being made available through a Remote Receiver Terminal that is receiving mission data via a SATCOM for use by field personnel. Alternatively, such a field computer can perform identical processing to that discussed above in connection ground station computer 17 in order to reconstruct, on its own, the complete situational imagery in real time.

Airborne Processor

[0069] In some embodiments, the aircraft-based elements shown in Figures 1 - 3 and discussed above are integrated into circuity depicted in Figures 11 - 13 and discussed below. Referred to as "ACIP," this integrates in a "plug & play" fashion all the airborne electronics & associated functions typically found in small tactical UAV, e.g.:

1. Sensor payload (Camera, radar, IR etc)

2. Avionics (INS-GPS, autopilot, see & avoid etc.)

3. Data-links (telemetry, satcom etc.)

4. Flight management

[0070] The ACIP stands in contrast to prior art tactical UAV systems, which often have control and payload modules as separate entities that run in a non-integrated manner, which creates following problems:

1. Complicated control & command mechanism.

2. Inefficient usage of payload space, communication bandwidth and other critical resources on board the UAS

3. Non-scalable and inflexible configuration. Capacity increase or payload type change are not easy tasks and often result in total redesign of the payload configuration and control software.

[0071] On the other hand, while designers of some modern aircrafts like corporate jets and airliners have incorporated an integrated approach in their on board avionics system, the technologies used in those systems are not applicable in a tactic UAV due to the dramatic differences in terms of piloting method (manned vs. unmanned), on board resources (payload space, power, etc.)

[0072] ACIP is aimed to solve the paradox of not having enough on board resources, but the need to have more control and communication capability of the UAS. The ACIP is designed to be a highly autonomous navigation system with collision avoidance capability and INS/GPS based redundant autopilot function. Yet it also provide highly reliable communication links to the ground control station using multiple technologies such as satellite, broadband wireless (Wifi and WiMAX), and VHF Radio Control.

Conclusions

[0073] Described herein are systems and methods meeting the objects set forth above, among others. It will be appreciated, of course, that the embodiments discussed here are merely examples of the invention and that other embodiments, varying from those shown here fall within the scope of the invention. Thus, by way of non-limiting example, it will be appreciated that the video camera 38 and video processor 28 may form a single unit, such as in the case of a digital video camera. Moreover, it will be appreciated that the SATCOM links (though, of generally low-speed relative to other forms of communication) may support transmission speeds higher (or lower) than those mentioned above.

Claims

1. A system (10) for unmanned vehicle operation, comprising

A. a control station (18),
B. a craft (12) disposed remotely from the control station (18),
C. an image acquisition device (38) coupled to the craft (12) and arranged for generating one or more images of one or more scenes in a vicinity of the craft (12),
D. a first digital data processor (14) coupled to the image acquisition device (38), the first digital processor (14) identifying anomalies in one or more scenes in one or more images generated by the image acquisition device (38) and transmitting alarms identifying actual or suspected natures of the anomalies,
E. a second digital data processor (17) disposed at the control station (18) in communications coupling with the first digital data processor (14), the second digital data processor (17) responding to the alarms transmitted from the first digital data processor (14) by generating images representative of the one or more scenes in which the anomalies were detected, and
F. wherein the first digital data processor (14) is coupled with the second digital data processor (17) by way of any of a low-bandwidth and/or small-antenna satellite link.

2. The system (10) of claim 1, wherein the craft (12) includes a dish antenna (60) that supports communications comprising the satellite link.

3. The system (10) of claim 1, wherein the satellite link supports communications of about 9600 bps (bytes per second) or less.

4. The system (10) of claim 2, wherein the image acquisition device (38) acquires video images of terrain, airspace, or other scenes in a vicinity of the craft (12).

5. The system (10) of claim 1, wherein the first digital data processor (14) is disposed on the craft (12).

6. The system (10) of claim 1, wherein the second digital data processor (17) is disposed at a distance that is beyond line of sight from the craft (12).

Patentansprüche

1. System (10) für einen unbemannten Fahrzeugbetrieb, umfassend:

A. eine Kontrollstation (18),
B. ein Gefährt (12), das entfernt von der Kontrollstation (18) angeordnet ist,
C. eine Bilderfassungseinrichtung (38), die an das Gefährt (12) gekoppelt und ausgelegt ist zum Generieren eines oder mehrerer Bilder einer oder mehrerer Szenen in einer Nähe des Gefährts (12),
D. einen ersten Digitaldatenprozessor (14), der an die Bilderfassungseinrichtung (38) gekoppelt ist, wobei der erste Digitalprozessor (14) Anomalien in einer oder mehreren Szenen in einem oder mehreren, durch die Bilderfassungseinrichtung (38) generierten Bildern identifiziert und Alarme sendet, die tatsächliche oder vermutete Arten der Anomalien identifizieren,
E. einen zweiten Digitaldatenprozessor (17), der bei der Steuerstation (18) in Kommunikationen angeordnet ist, die mit dem ersten Digitaldatenprozessor (14) koppeln, wobei der zweite Digitaldatenprozessor (17) auf die von dem ersten Digitaldatenprozessor (14) übertragenen Alarme reagiert durch Generieren von Bildern, die die eine oder mehreren Szenen darstellen, in denen die Anomalien detektiert wurden, und
F. wobei der erste Digitaldatenprozessor (14) mit dem zweiten Digitaldatenprozessor (17) durch eine Satellitenstrecke mit niedriger Bandbreite und/oder einer kleinen Antenne gekoppelt ist.

2. System (10) nach Anspruch 1, wobei das Gefährt (12) eine Parabolantenne (60) enthält, die Kommunikationen unterstützt, die die Satellitenstrecke umfassen.

3. System (10) nach Anspruch 1, wobei die Satellitenstrecke Kommunikationen von etwa 9600 bps (Bytes pro Sekunde) oder weniger unterstützt.

4. System (10) nach Anspruch 2, wobei die Bilderfassungseinrichtung (38) Videobilder von Gelände, Luftraum oder anderen Szenen in einer Nähe des Gefährts (12) erfasst.

5. System (10) nach Anspruch 1, wobei der erste Digitaldatenprozessor (14) an dem Gefährt (12) angeordnet ist.

6. System (10) nach Anspruch 1, wobei der zweite Digitaldatenprozessor (17) in einer Distanz angeordnet ist, die sich jenseits der Blicklinie vom Gefährt (12) befindet.

Revendications

1. Système (10) destiné à des opérations de véhicules sans pilote, comprenant

A. une station de commande (18),
B. un aéronef (12) disposé à distance de la station de commande (18),
C. un dispositif d'acquisition d'images (38) couplé à l'aéronef (12) et agencé pour générer une ou plusieurs images d'une ou de plusieurs scènes au voisinage de l'aéronef (12),
D. un premier processeur de données numériques (14) couplé au dispositif d'acquisition d'images (38), le premier processeur numérique (14) identifiant des anomalies dans une ou plusieurs scènes dans une ou plusieurs images générées par le dispositif d'acquisition d'images (38) et transmettant des alarmes identifiant les natures réelles ou suspectées des anomalies,
E. un second processeur de données numériques (17) disposé au niveau de la station de commande (18) couplé de manière à communiquer avec le premier processeur de données numériques (14), le second processeur de données numériques (17) répondant aux alarmes transmises par le premier processeur de données numériques (14) en générant des images représentatives des unes ou plusieurs scènes dans lesquelles les anomalies ont été détectées, et
F. dans lequel le premier processeur de données numériques (14) est couplé au second processeur de données numériques (17) au moyen de l'une quelconque d'une liaison à faible largeur de bande et/ou d'une liaison satellitaire à petite antenne.

2. Système (10) selon la revendication 1, dans lequel l'aéronef (12) comporte une antenne parabolique (60) qui prend en charge les communications comprenant la liaison satellitaire.

3. Système (10) sur la revendication 1, dans lequel la liaison satellitaire prend en charge des communications d'environ 9600 bps (octets par seconde).

4. Système (10) sur la revendication 2, dans lequel le dispositif d'acquisition d'images (38) acquiert des images vidéo du relief, de l'espace aérien, ou d'autres scènes au voisinage de l'aéronef (12).

5. Système (10) sur la revendication 1, dans lequel le premier processeur de données numériques (14) est disposé sur l'aéronef (12).

6. Système (10) sur la revendication 1, dans lequel le second processeur de données numériques (17) est disposé à une distance dépassant la ligne de vision depuis l'aéronef (12).

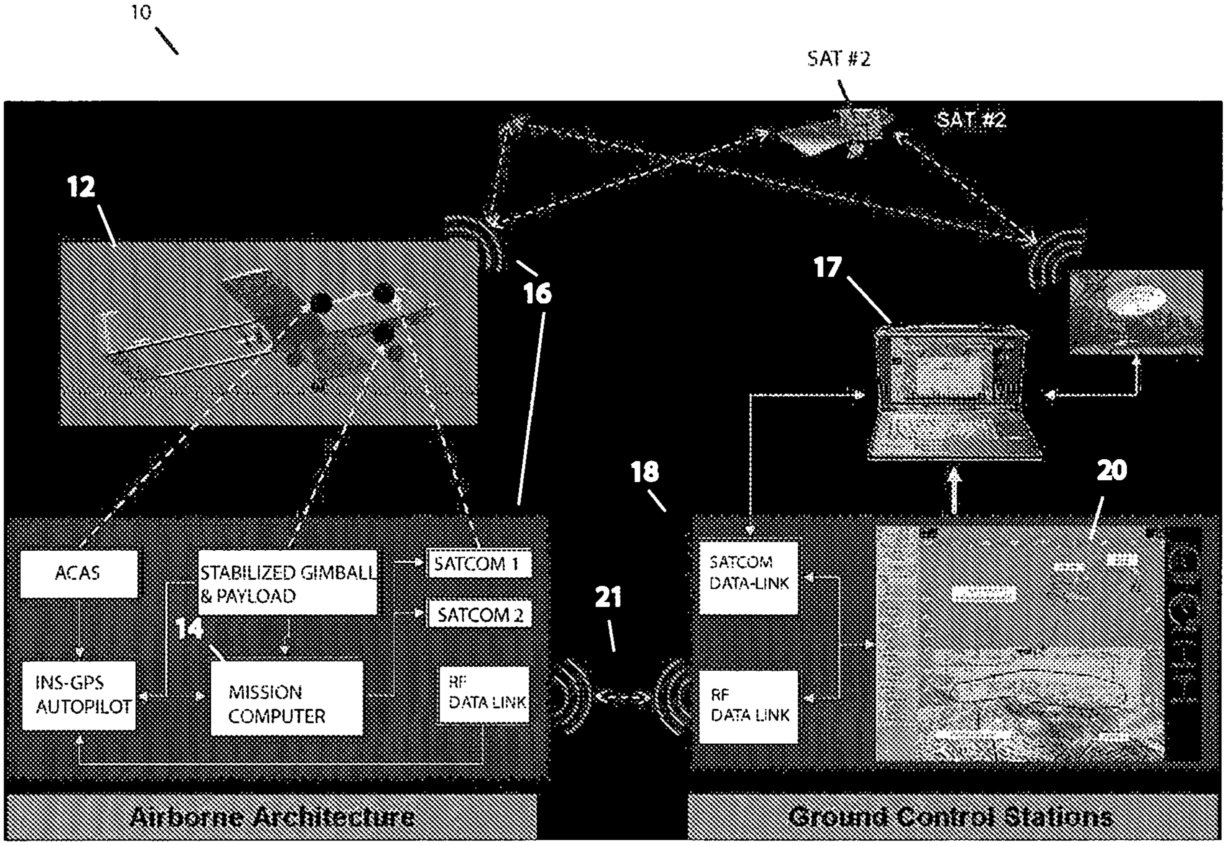

10
SAT #2
SAT #2
12
16
17
18
20
21
14
ACAS
STABILIZED GIMBALL & PAYLOAD
SATCOM 1
SATCOM 2
INS-GPS AUTOPILOT
MISSION COMPUTER
RF DATA LINK
SATCOM DATA-LINK
RF DATA LINK
Airborne Architecture
Ground Control Stations

Figure 1

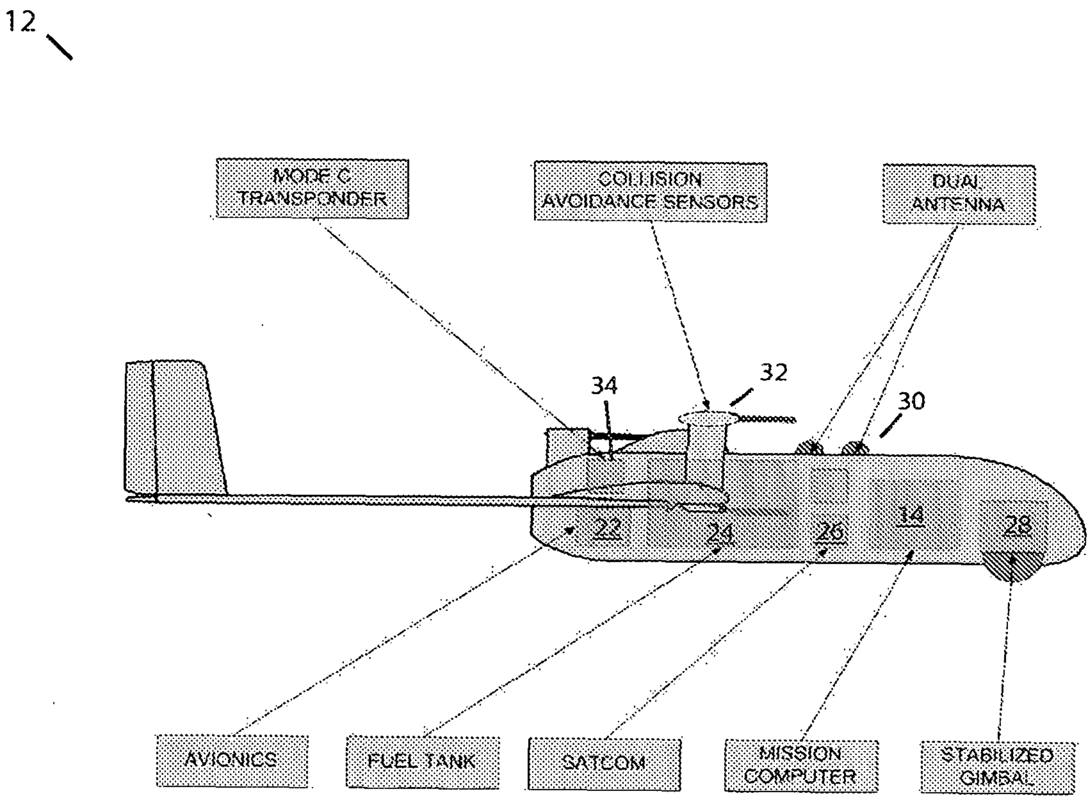

12
MODE C TRANSPONDER
COLLISION AVOIDANCE SENSORS
DUAL ANTENNA
34
32
30
22
24
26
14
28
AVIONICS
FUEL TANK
SATCOM
MISSION COMPUTER
STABILIZED GIMBAL

Figure 2

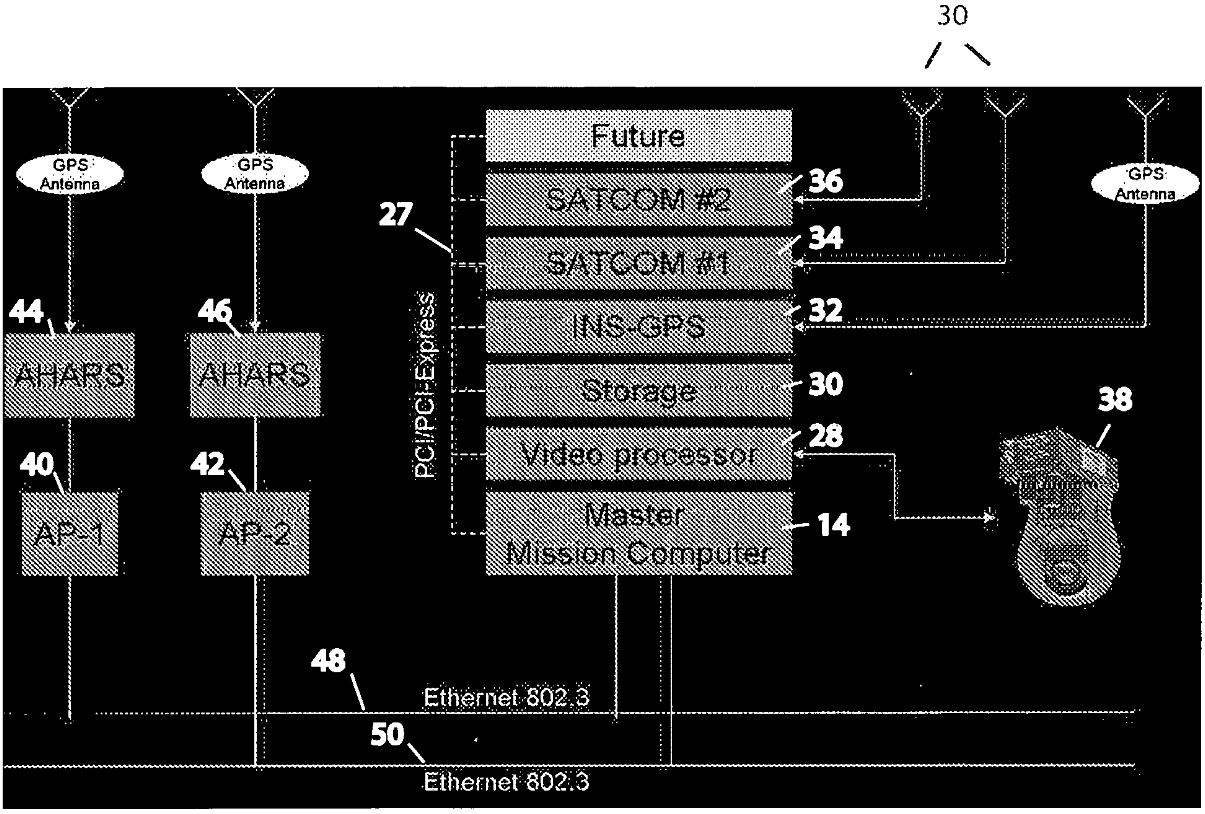

30
Future
SATCOM #2
36
SATCOM #1
34
INS-GPS
32
Storage
30
Video processor
28
Master
Mission Computer
14
38
27
PCI/PCI-Express
GPS Antenna
GPS Antenna
GPS Antenna
44
46
AHARS
AHARS
40
42
AP-1
AP-2
48
Ethernet 802.3
50
Ethernet 802.3

Figure 3

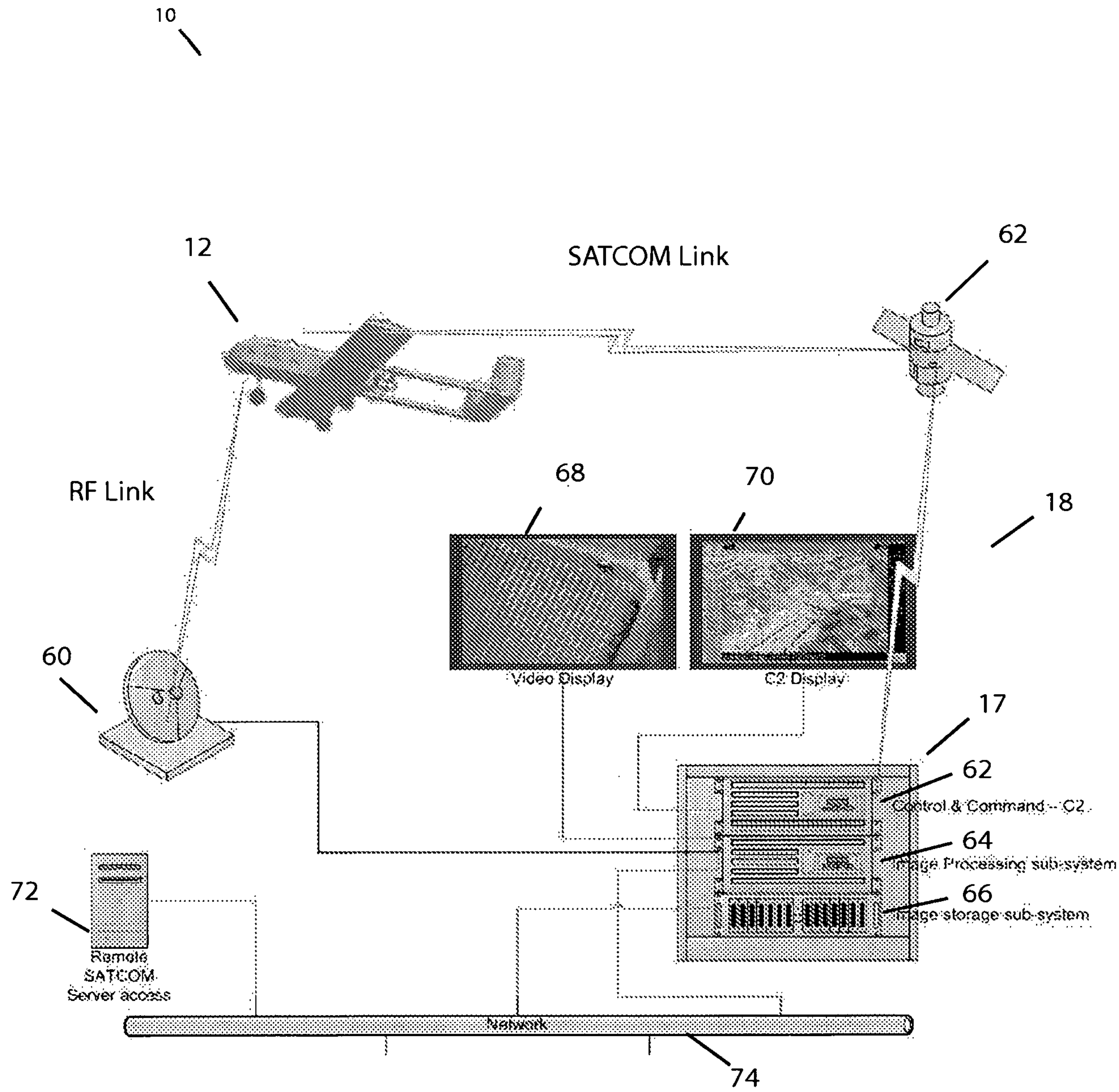

10
12
SATCOM Link
62
RF Link
68
70
18
60
Video Display
C2 Display
17
62
Control & Command – C2
64
Image Processing sub-system
66
Image storage sub-system
72
Remote
SATCOM
Server access
Network
74

Figure 4

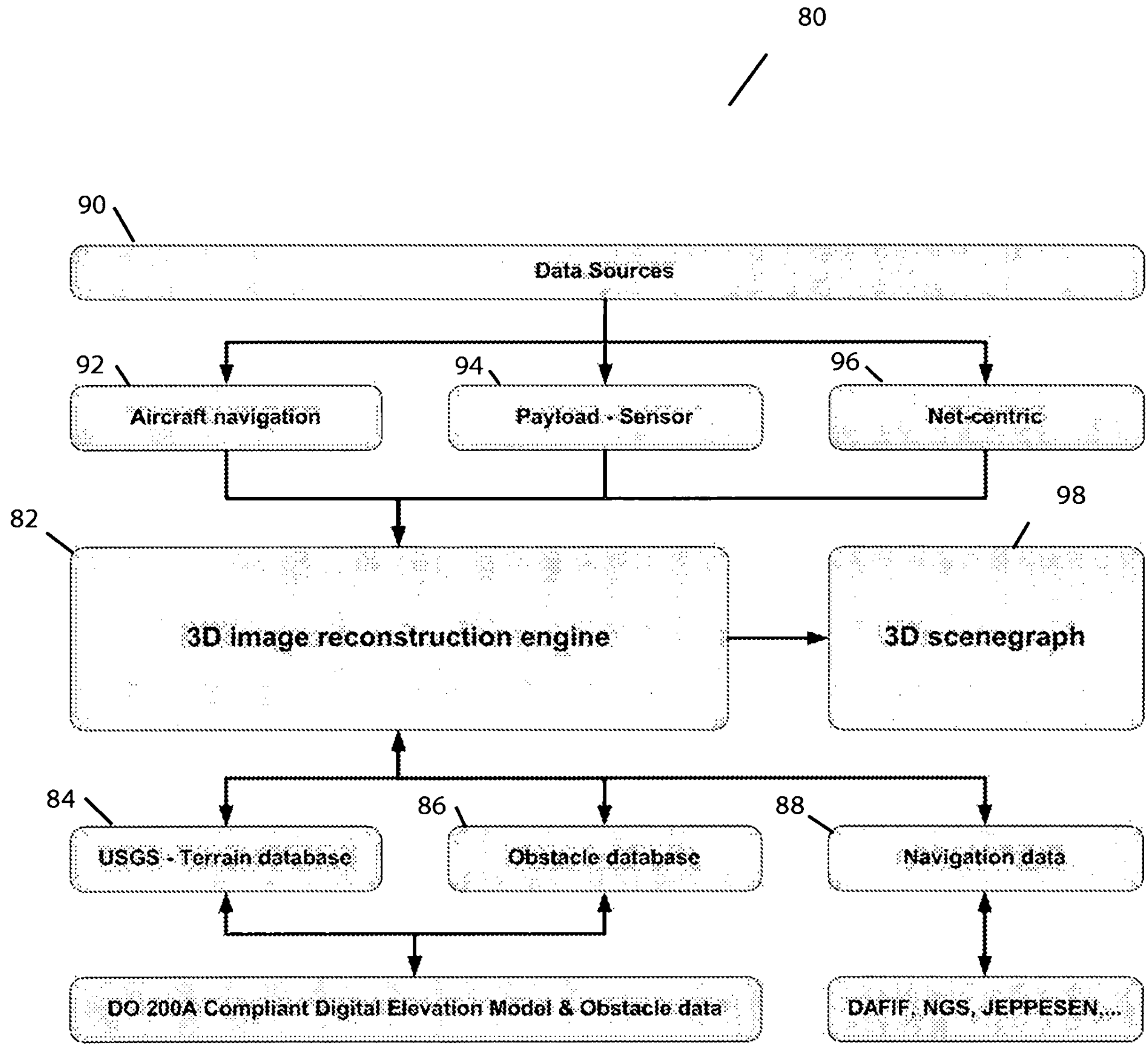

80
90
Data Sources
92
Aircraft navigation
94
Payload - Sensor
96
Net-centric
82
3D image reconstruction engine
98
3D scenegraph
84
USGS - Terrain database
86
Obstacle database
88
Navigation data
DO 200A Compliant Digital Elevation Model & Obstacle data
DAFIF, NGS, JEPPESEN,...

Figure 5

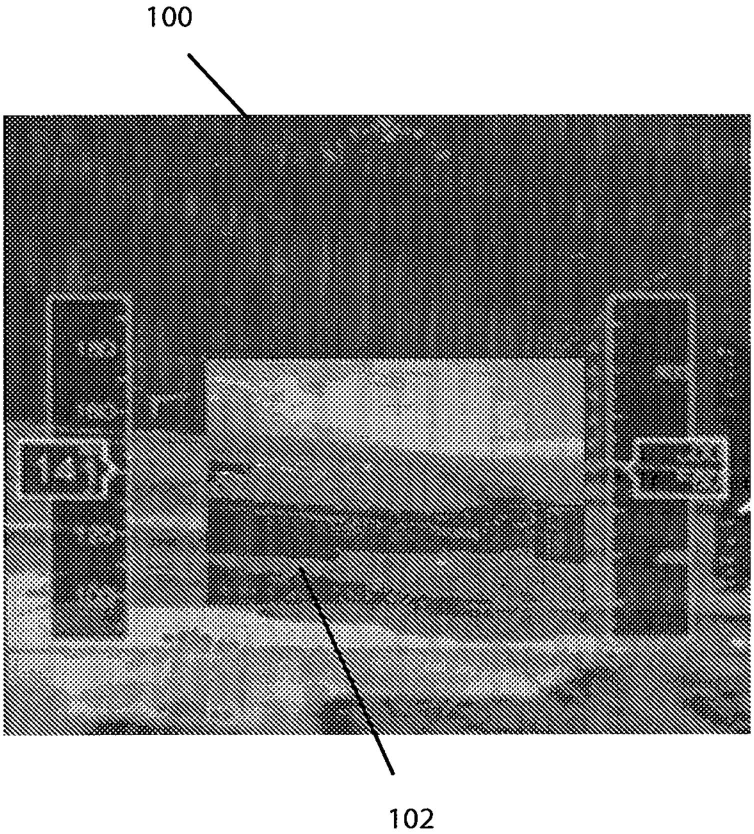


Figure 6a

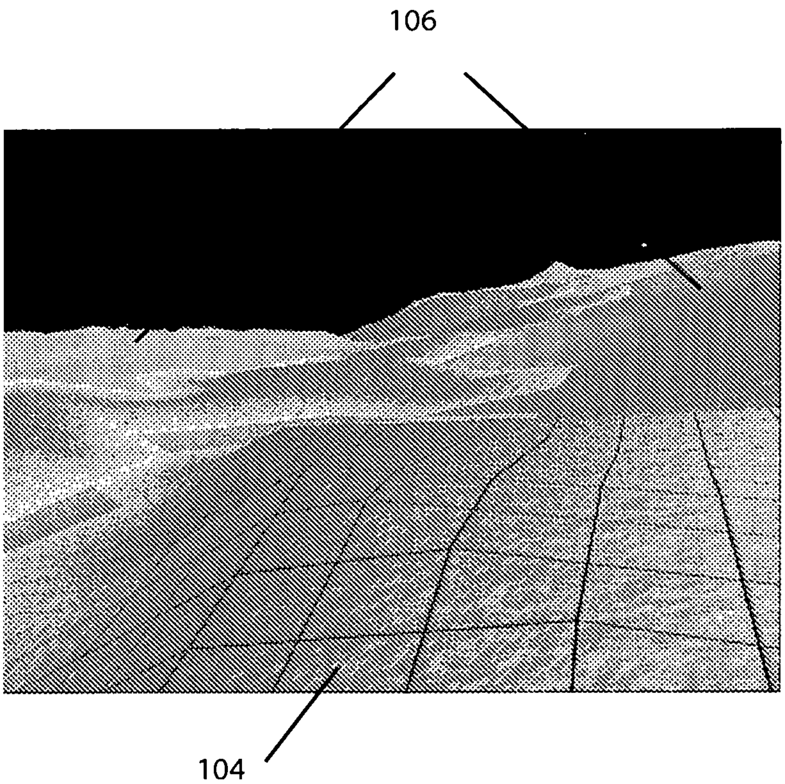


Figure 6b

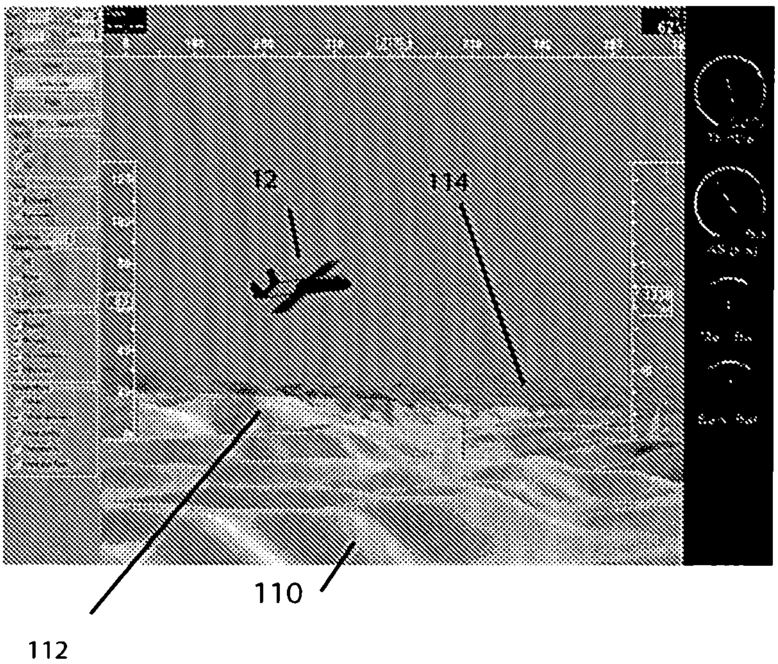


Figure 7

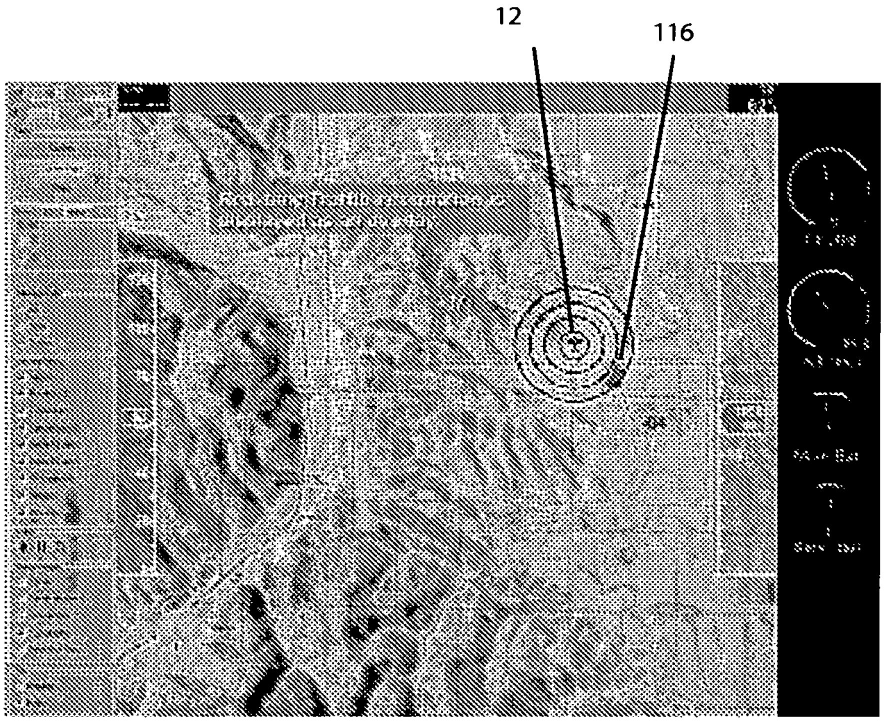


Figure 8

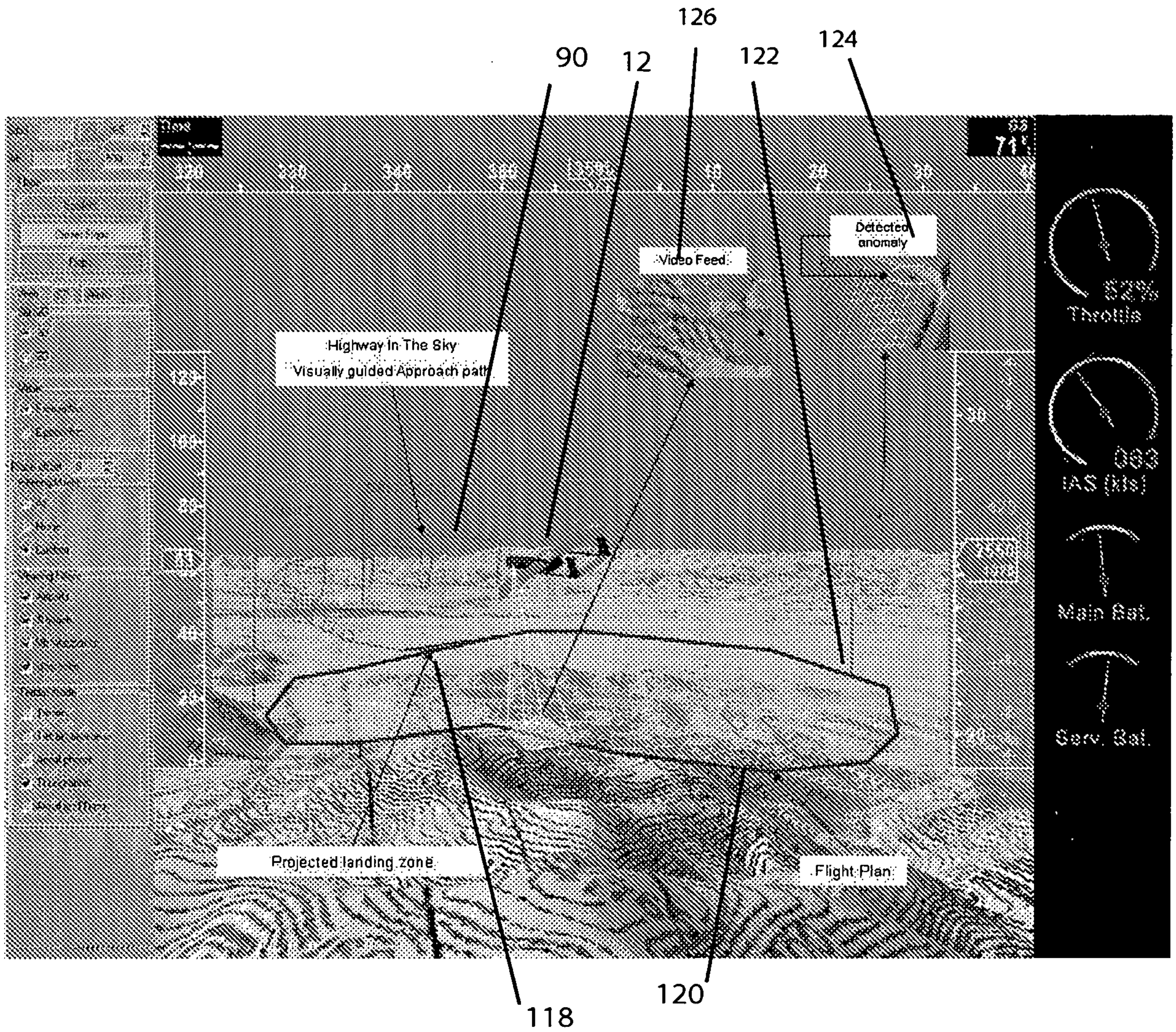

126
90
12
122
124
Detected anomaly
Video Feed
Highway In The Sky
Visually guided Approach path
Throttle
IAS (kts)
Main Bat.
Serv. Bat.
Projected landing zone
Flight Plan
118
120

Figure 9

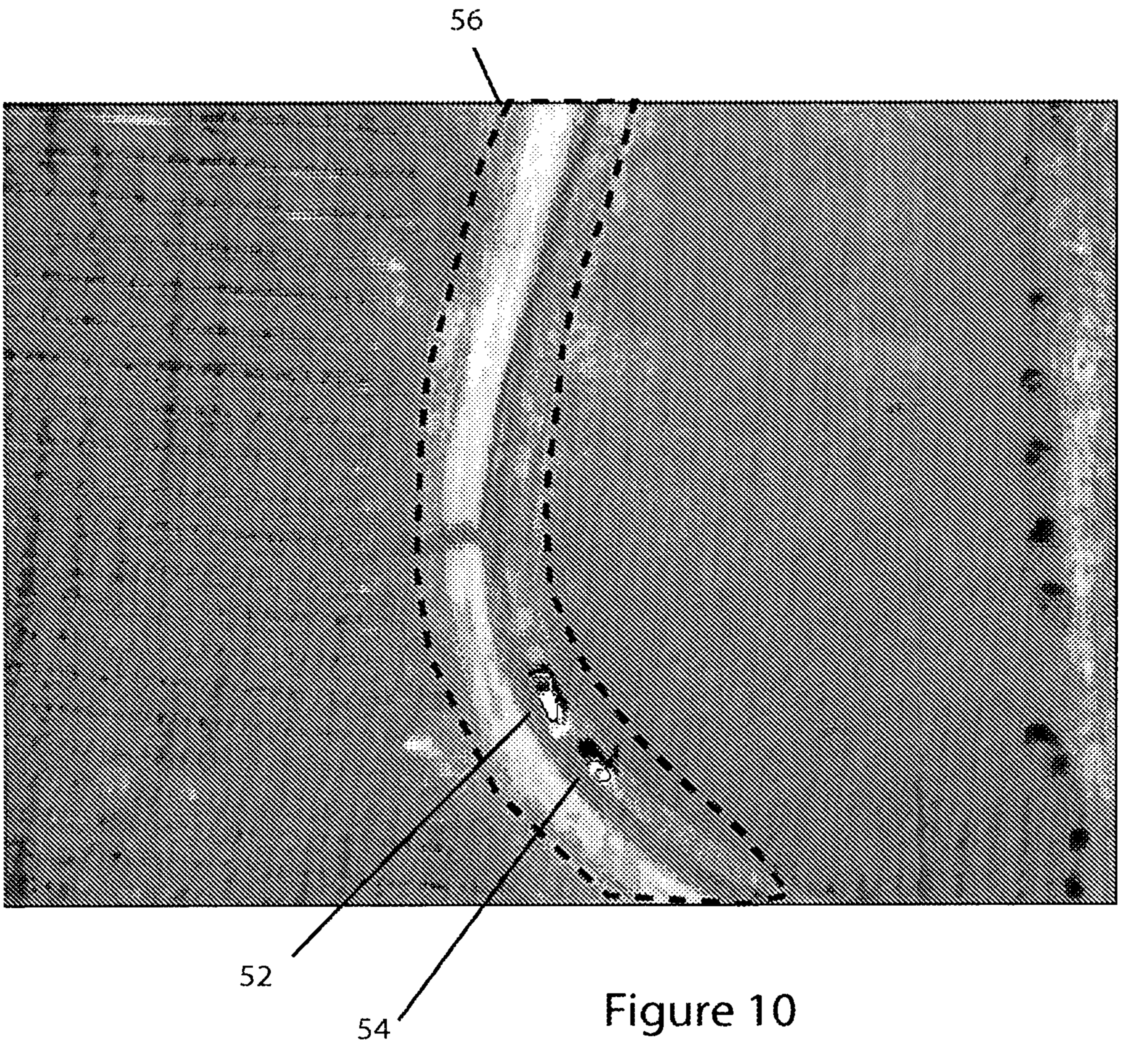


Figure 10

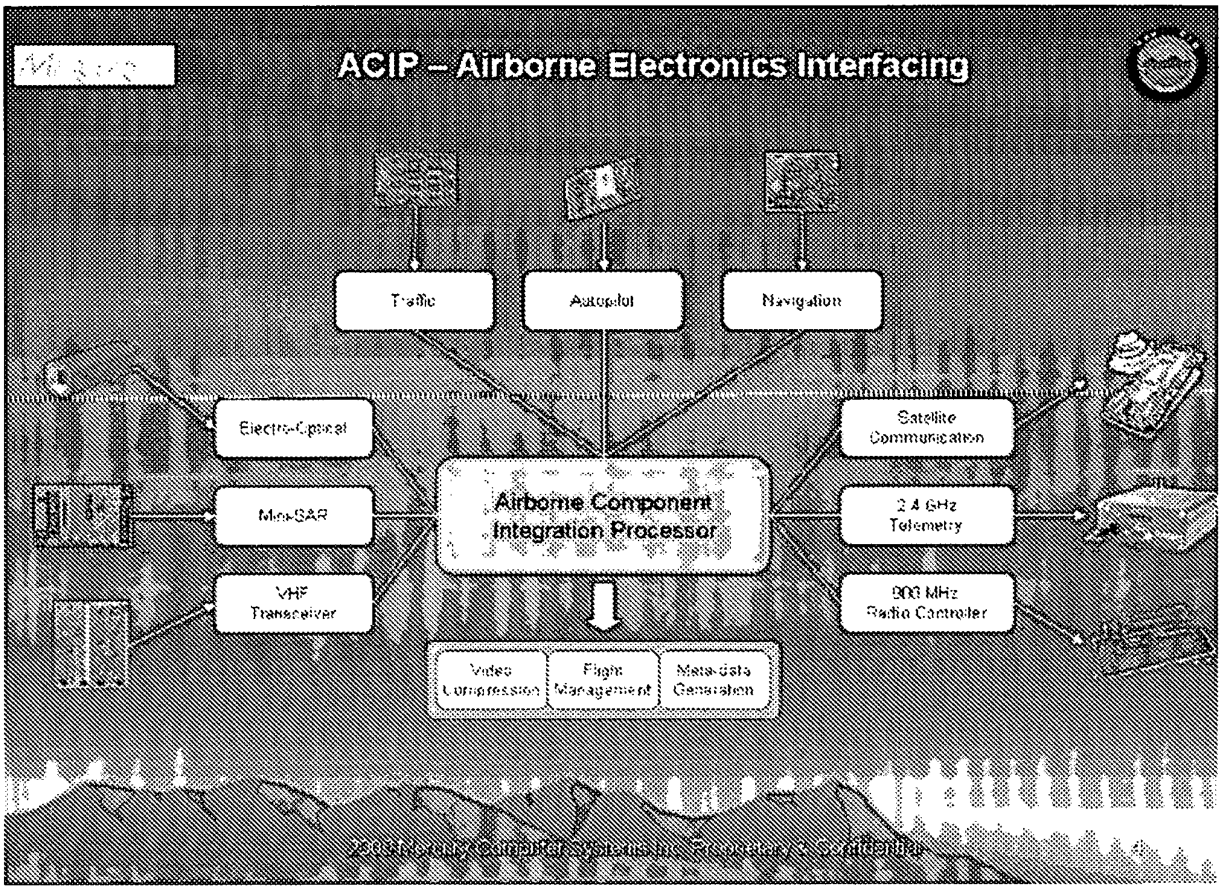
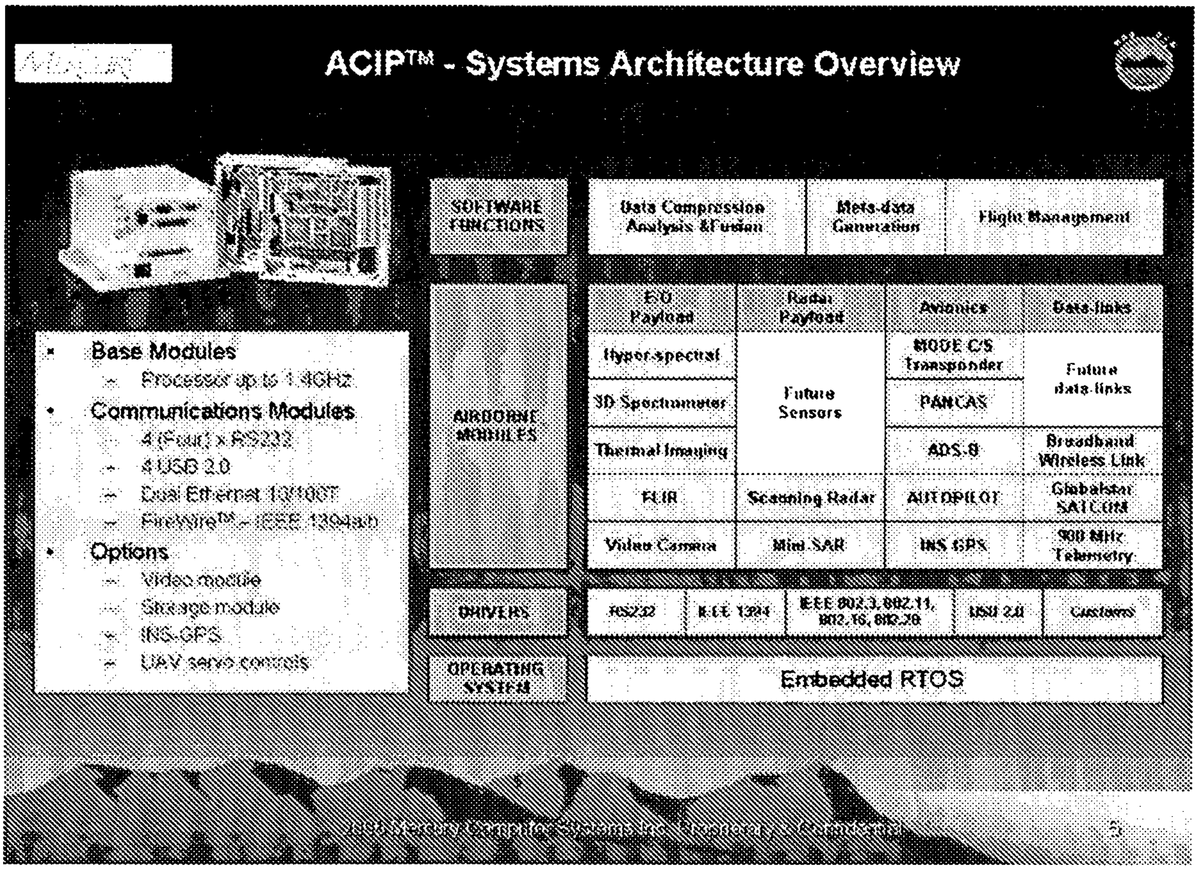

ACIP – Airborne Electronics Interfacing
Traffic
Autopilot
Navigation
Electro-Optical
Mini-SAR
VHF Transceiver
Airborne Component Integration Processor
Satellite Communication
2.4 GHz Telemetry
900 MHz Radio Controller
Video Compression
Flight Management
Meta-data Generation

Figure 11



ACIP™ - Systems Architecture Overview
Base Modules
Communications Modules
Options
SOFTWARE FUNCTIONS
Data Compression Analysis &Fusion
Meta-data Generation
Flight Management
AIRBORNE MODULES
E/O Payload
Radar Payload
Avionics
Data-links
Hyper-spectral
3D Spectrometer
Thermal Imaging
FLIR
Video Camera
Future Sensors
Scanning Radar
Mini-SAR
MODE C/S Transponder
PANCAS
ADS-B
AUTOPILOT
INS GPS
Future data-links
Broadband Wireless Link
Globalstar SATCOM
900 MHz Telemetry
DRIVERS
RS232
IEEE 1394
IEEE 802.3, 802.11, 802.16, 802.20
USB 2.0
Custom
OPERATING SYSTEM
Embedded RTOS

Figure 12

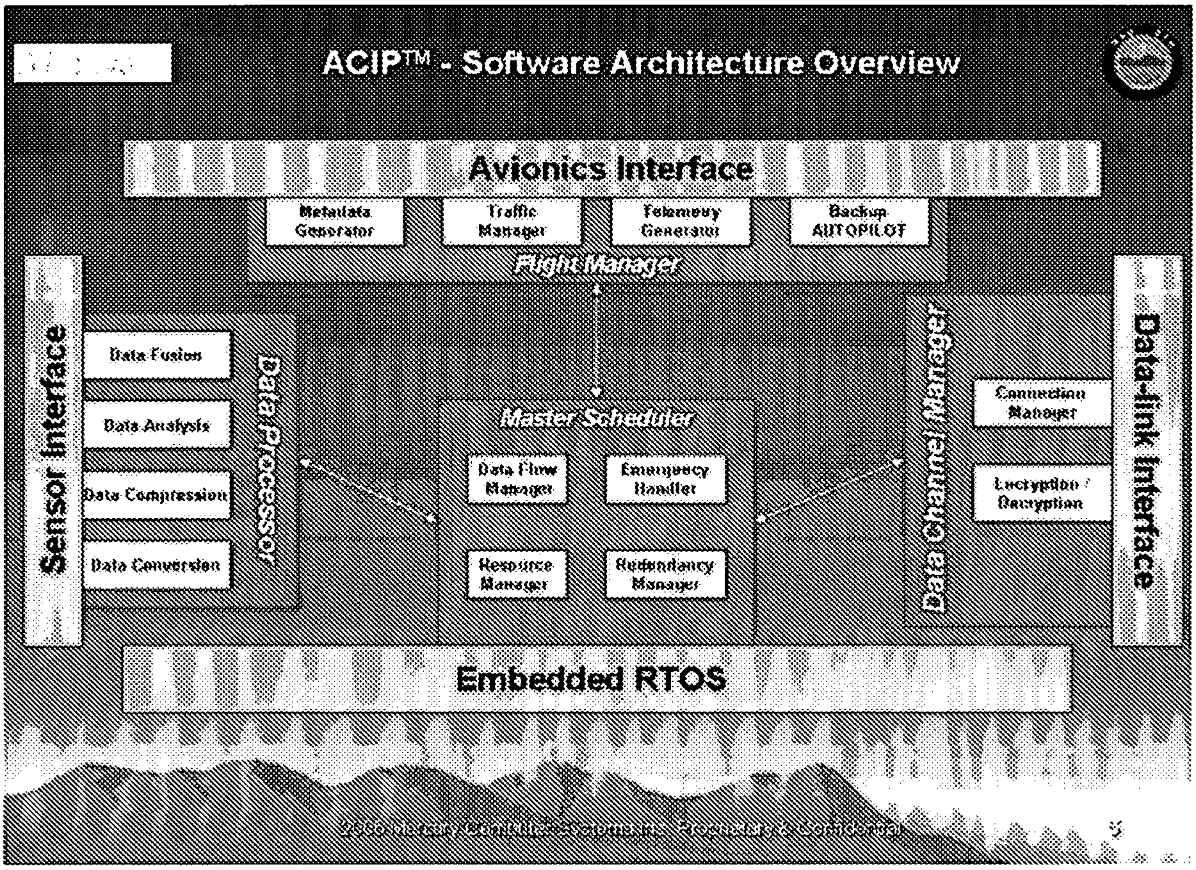

ACIP™ - Software Architecture Overview
Avionics Interface
Metadata Generator
Traffic Manager
Telemetry Generator
Backup AUTOPILOT
Flight Manager
Sensor Interface
Data Fusion
Data Analysis
Data Compression
Data Conversion
Data Processor
Master Scheduler
Data Flow Manager
Emergency Handler
Resource Manager
Redundancy Manager
Data Channel Manager
Connection Manager
Encryption / Decryption
Data-link Interface
Embedded RTOS

Figure 13

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 2005113987 A1 **[0005]**
- WO 0158758 A2 **[0006]**
- US 6064428 A **[0007]**

Non-patent literature cited in the description

- **WINTER et al.** Hyperspectral image sharpening using multispectral data,'' Algorithms and Technologies for Multispectral, Hyperspectral, and Ultraspectral Imagery XI. *Proceedings of the SPIE,* 2005, vol. 5806, 794-803 **[0030]**
- **I. S. REED ; X. YU.** Adaptive multiple-band CFAR detection of an optical pattern with unknown spectral distribution. *IEEE Trans. Acoust.,Speech, Signal Processing,* October 1990, vol. 38, 1760-1770 **[0030]**